ASME PCC-2S–2015

Supplement to ASME PCC-2–2015

Repair of Pressure Equipment and Piping

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The American Society of Mechanical Engineers
Two Park Avenue, New York, NY 10016-5990

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APPLICATION OF THIS SUPPLEMENT

(This is a special Supplement to the ASME PCC-2–2015 Standard.)

The ASME PCC Standards Committee opened a technical revision in 2010 to address repair welding considerations for pressure vessels made from Cr–Mo steels in refinery, petrochemical, power generation, and other services. The Committee developed the high-level overview of deterioration mechanisms and the subsequent factors to consider in developing a detailed repair, examination, and testing plan for the successful repair of such pressure vessels.

Article 2.15 in this Supplement applies to the post-construction repair welding of Cr–Mo steel pressure vessels and is part of the ASME PCC-2–2015 Standard.

PART 2
WELDED REPAIRS

Article 2.15
Repair Welding Considerations for Cr–Mo Steel Pressure Vessels

1 DESCRIPTION

1.1 Scope

Repair welding considerations in this Article are applicable to pressure vessels for refinery, petrochemical, power generation, and other services where the requirements of this Article apply. Table 1 provides guidance for the applicability of repair welding for Cr–Mo steel pressure vessels.

1.2 Application

(a) This Article describes weld repair considerations for pressure vessels made from Cr–Mo steels. The purpose of this Article is to provide a high-level overview of deterioration mechanisms and the subsequent factors that need to be considered in developing a detailed repair, examination, and testing plan for the successful repair of Cr–Mo pressure vessels.

(b) The Cr–Mo materials listed in Table 2 of this Article are susceptible to certain types of damage in elevated-temperature service (e.g., see WRC Bulletins 488, 489, and 490).

(c) The repair of creep-damaged Cr–Mo steels, creep-enhanced ferritic steels, vanadium-modified steels, or stainless steel cladding or weld overlay are not included in this Article. See ASME PCC-2, Article 2.11 for information on weld overlay and clad restoration; creep will be covered in a separate Article in a future edition of ASME PCC-2.

(d) API RP 571 and API RP 579-1/ASME FFS-1 provide further information on temper embrittlement and other aging effects on the fracture toughness of Cr–Mo steels.

1.3 Design Temperature

The maximum design temperatures of Cr–Mo materials are as listed in the applicable codes of construction.

1.4 Applicable Materials

Typical Cr–Mo materials and their ASME designations are indicated in Table 2; however, equivalent international standard materials may also be used.

2 LIMITATIONS

ASME PCC-2, Part 1 contains additional requirements. This Article shall be used in conjunction with ASME PCC-2, Part 1.

3 DESIGN

3.1 Feasibility Study of Repair Welding

(a) The materials listed in Table 2 may be repair welded provided an investigation has been performed to determine the cause of the damage to be repaired and provided appropriate weld repair procedures are used.

(b) The following should be assessed prior to performing repair welding:

(1) the structural integrity of the pressure vessel

(2) the feasibility of the repairs

(3) the suitability of the pressure vessel for the intended service after the repairs are completed

The serviceability or fitness-for-service assessment should be based on API RP 579-1/ASME FFS-1, as shown in Fig. 1.

3.2 Consideration of In-Service Degradation

(a) In-service degradation (see Table 3 and Fig. 2) shall be considered before developing a repair welding procedure.

(b) Typical considerations for in-service degradation for weld repair are shown in Table 4.

(c) Further information on in-service degradation is provided in API RP 571 and in WRC Bulletins 488, 489, and 490.

3.3 Examples of Damage

Figure 2 shows examples of damage that can occur in Cr–Mo pressure vessels with or without stainless steel cladding or weld overlay. The examples are typical of high-temperature, high-pressure (HTHP) pressure vessels in refining service.

3.4 Development of Weld Repair Procedures

(a) The selection of weld repair method should be based on the reliability of the repaired area considering the future operation period, as shown in Fig. 3.

(b) Sleeve repair and partial patch repair methods (see Table 5) are normally applied temporarily and are not recommended for periods beyond the next upcoming shutdown or outage without appropriate nondestructive examination (NDE) and applicable fitness-for-service assessment.

3.5 Repair Welding Methods Applicable to Cr–Mo Vessels

Some applicable repair welding approaches and alternatives to postweld heat treatment (PWHT) and the ASME PCC-2 Articles in which they are described are listed in Table 5, along with some additional limitations and considerations.

3.6 Welding and Preheat

When the actual aged condition of the component to be repaired cannot be sufficiently evaluated for development of a repair welding procedure, a bead-on plate test should be used to verify the repair welding procedure.

NOTE: A bead-on plate test is a type of self-restraint weld test used to evaluate the cracking sensitivity of the base materials and arc welding consumables. Refer to Kayano et al. and Yamamoto et al. (see section 7, References).

4 FABRICATION

4.1 Weld Repair Procedures

(a) Weld repair procedures may be developed as indicated in Table 6.

(b) The welding procedure specification (WPS) shall be qualified in accordance with ASME BPVC Section IX, as applicable, and/or the requirements imposed by the applicable code of construction.

4.2 Preparation for Welding

(a) For shielded metal arc welding (SMAW), drying of electrodes shall be carried out to minimize the potential for hydrogen cracking.

(b) Welding bevel surfaces shall be clean, dry, and free of oil, paint, or other contaminants.

4.3 Welding Conditions

(a) To prevent hardening of welds, weld beads less than 50 mm (2 in.) in length should be avoided.

(b) Special precaution shall be taken to guard against brittle fracture due to local thermal temperature gradients.

(c) For one-side repair welding of piping, back shielding should be considered for $2\frac{1}{4}$Cr–1Mo and higher alloy steels.

(d) The temper bead welding method may be considered after evaluation in some cases for low alloy welds when PWHT will not be carried out. See para. 4.7.

4.4 Preheating and Post-Heating

(a) To prevent hardening of welds and cold cracking, preheating, post-heating, and dehydrogenation heat treatment (DHT) shall be mandatory unless paras. 4.5 through 4.7 stipulate otherwise.

(b) Typical preheating and welding interpass temperatures are indicated in Table 7.

4.5 De-Embrittlement Heat Treatment

When the materials are severely embrittled, a de-embrittlement heat treatment operation may be used to recover toughness of material, as shown in Table 8.

4.6 Dehydrogenation Heat Treatment

The preheat temperature should be maintained until PWHT or DHT is performed. When the materials are required to cool to ambient temperature after repair welding, dehydrogenation heating shall be carried out at a minimum of 300°C (570°F) for a minimum of 1 h, or for a duration to be agreed upon between the purchaser and fabricator, to prevent cold cracking.

4.7 Postweld Heat Treatment

(a) PWHT should be performed when required per applicable construction codes or standards.

(b) Temper bead and other welding methods as detailed in ASME PCC-2, Article 2.9 may be applicable to some low-chrome steels when corresponding WPSs or procedure qualification records (PQRs) are developed specifically for the welding repair considering welding position and welding circumstances.

(c) Temper bead methods are usually not appropriate for $2\frac{1}{4}$Cr–1Mo and higher-chrome materials used for hydrogen service because of the high weld-metal and heat-affected zone (HAZ) hardnesses generated by the welding process.

(d) In case of local PWHT, the PWHT procedure developed shall include the arrangement of thermocouples and insulation to minimize the thermal stresses generated during the PWHT operation. AWS D10.10 and WRC Bulletin 452 provide guidelines for developing a PWHT plan with specific band widths (soak band, heated band, and gradient control band) to ensure that thermal gradients are not harmful.

5 EXAMINATION

(a) NDE, as indicated in Table 6, shall be considered at each appropriate step of repair welding work. The appropriate NDE procedure(s) for the applicable repair shall be selected to meet the requirements of the applicable code of construction and to provide the level of examination necessary for the repair.

(b) NDE procedures shall be in accordance with ASME BPVC Section V and applicable construction codes and standards.

(c) NDE before repair welding of pressure boundary shall include the following:

(1) The entire area of the pressure vessel that is to be repair welded shall be examined by means of visual examination (VT) or other NDE methods as may be applicable to ensure that the area is free of any defect harmful to the repair operation, which may include welding, PWHT, and pressure testing.

(2) The need for carrying out pressure testing after repairs as well as the pressure used in pressure testing shall be evaluated in consideration of service conditions.

(d) NDE after weld repair and after pressure test shall include the following:

(1) Complete NDE shall be performed in an area that is at least the maximum of either $2T$, where T is the thickness of material, or 100 mm (4 in.) from the edge of the repair-welded, preheated, or postweld heat-treated area, to ensure the area is free of defects.

(2) NDE of the area described in (1) shall also be performed after any pressure test is carried out.

(e) Acoustic emission testing may also be an effective means of examination following completion of repairs.

(f) Where possible, in-service NDE monitoring during operation is recommended for the repaired areas.

(g) In some instances, NDE may be used in lieu of pressure testing for repairs. Refer to ASME PCC-2, Article 5.2.

(h) Follow-up NDE after the pressure vessel is returned to service shall be performed based on fitness-for-service assessment requirements or applicable international surveys industry (ISI) codes.

6 PRESSURE TESTING

(a) The requirement for the applicability of a pressure test subsequent to weld repairs shall be evaluated.

(b) If a pressure test is determined to be required after the repair welding of pressure-bearing parts is completed, the pressure vessel or vessel part should be pressure tested in accordance with the requirements of the applicable construction code. If the applicable construction code has no such pressure test requirements, ASME PCC-2, Article 5.1 should be followed.

(c) The pressure test, when required, shall be performed at a temperature higher than the fracture appearance transition temperature (FATT) and at or above the minimum temperature specified by the applicable code of construction, to prevent brittle fracture during the pressure test.

(d) The toughness value of degraded materials shall be evaluated based on accumulated material database or samples obtained from vessel parts.

(e) For pressure vessels that operate in hydrogen service and are to be hydrotested, the hydrotest pressure shall be evaluated in consideration of hydrogen service conditions and shall be no higher than the vessel operating pressure.

(f) When a pressure test is to be carried out, consideration shall be given to the pressure train that the pressure vessel is located in, the possibility of isolation of components within that train, and the need for pressure testing the entire train.

7 REFERENCES

API RP 571, 2011, Damage Mechanisms Affecting Fixed Equipment in the Refining Industry

API RP 579-1/ASME FFS-1 2007, Fitness-For-Service

API RP 934-A, Materials and Fabrication of 2¼Cr–1Mo, 2¼Cr–1Mo–¼V, 3Cr–1Mo, and 3Cr–1Mo–¼V Steel Heavy Wall Pressure Vessels for High-Temperature, High-Pressure Hydrogen Service

API RP 934-C, Materials and Fabrication of 1¼Cr–½Mo Steel Heavy Wall Pressure Vessels for High-Pressure Hydrogen Service Operating at or Below 825°F (441°C)

API RP 934-E, Recommended Practice for Materials and Fabrication of 1¼Cr–½Mo Steel Pressure Vessels for Service Above 825°F (440°C)

API RP 941, Steels for Hydrogen Service at Elevated Temperatures and Pressures in Petroleum Refineries and Petrochemical Plants

API TR 934-D, Technical Report on the Materials and Fabrication Issues of 1¼Cr–½Mo and 1Cr–½Mo Steel Pressure Vessels

Publisher: American Petroleum Institute (API), 1220 L Street, NW, Washington, DC 20005 (www.api.org)

ASME Boiler and Pressure Vessel Code, Section V, Nondestructive Examination

ASME Boiler and Pressure Vessel Code, Section IX, Welding, Brazing, and Fusing Qualifications

ASME PCC-3, Inspection Planning Using Risk-Based Methods

Kayano, R., Abe, M., and Hirai, Y., "Guidelines for Repair Welding of Pressure Equipment in Refineries and Chemical Plants: Part 3 — Carbon Steel, High Tensile Steel and Cr–Mo Steel," paper no. PVP2011-57079 from the Proceedings of the ASME 2011 Pressure Vessels and Piping Conference, July 2011

Tahara, T., Antalffy, L. P., Kayano, R., and Tsutomu, K., "Chronological Review of Manufacturing Technologies and Considerations of Maintenance/

Inspection for Heavy Wall Hydroprocessing Reactors," paper no. PVP2013-97227 from the Proceedings of the ASME 2013 Pressure Vessels and Piping Conference, July 2013

Yamamoto, E., Tahara, T., Matsushita, Y., and Minami, F., "Guidelines for Repair Welding of Pressure Equipment in Refineries and Chemical Plants: Part 1 — General," paper no. PVP2011-57809 from the Proceedings of the ASME 2011 Pressure Vessels and Piping Conference, July 2011

Publisher: The American Society of Mechanical Engineers (ASME), Two Park Avenue, New York, NY 10016-5990; Order Department: 22 Law Drive, P.O. Box 2900, Fairfield, NJ 07007-2900 (www.asme.org)

Atkins, D., Thiessen, D., Nissley, N., and Adonyi, Y., "Welding Process Effects in Weldability Testing of Steels," *Welding Journal*, April 2002

AWS D10.10/D10.10M, Recommended Practices for Local Heating of Welds in Piping and Tubing

Publisher: American Welding Society (AWS), 8669 NW 36 Street, No. 130, Miami, FL 33166 (www.aws.org)

BS EN ISO 17642-2:2005, Destructive test on welds in metallic materials — Cold cracking tests for weldments — Arc welding processes, Part 2: Self-restraint tests

Publisher: British Standards Institution, Inc. (BSI), 12950 Worldgate Drive, Suite 800, Herndon, VA 20170 (www.bsigroup.com)

WRC Bulletin 452, Recommended Practices for Local Heating of Welds in Pressure Vessels

WRC Bulletin 488, Damage Mechanisms Affecting Fixed Equipment in the Pulp and Paper Industry

WRC Bulletin 489, Damage Mechanisms Affecting Fixed Equipment in the Refining Industry

WRC Bulletin 490, Damage Mechanisms Affecting Fixed Equipment in the Fossil Electric Power Industry

Publisher: Welding Research Council (WRC), P.O. Box 201547, Shaker Heights, OH 44122 (www.forengineers.org/welding-research-council)

Fig. 1 Standard Steps in Repair Welding

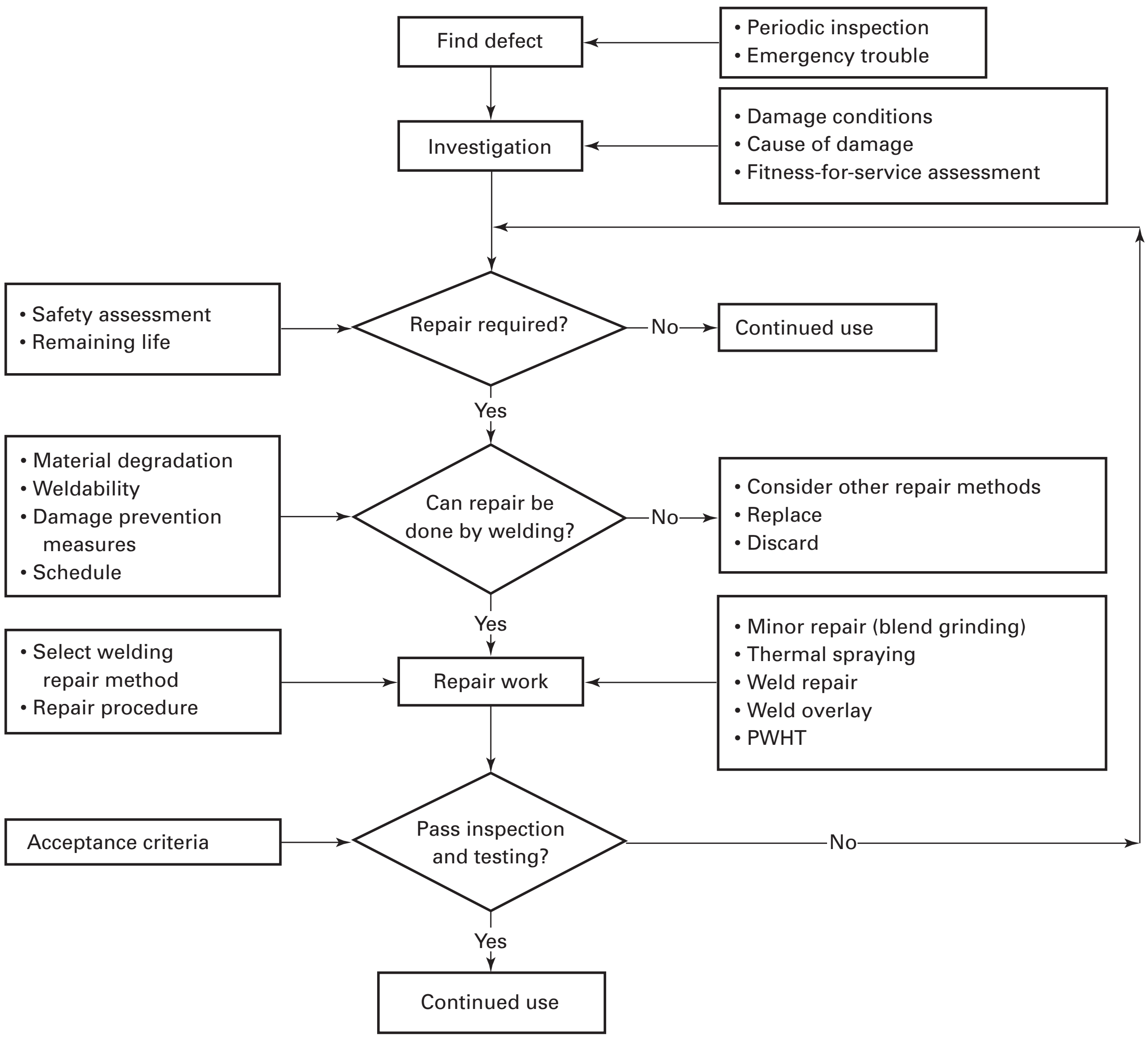

Fig. 2 Examples of Damage Common to Cr–Mo Pressure Vessels

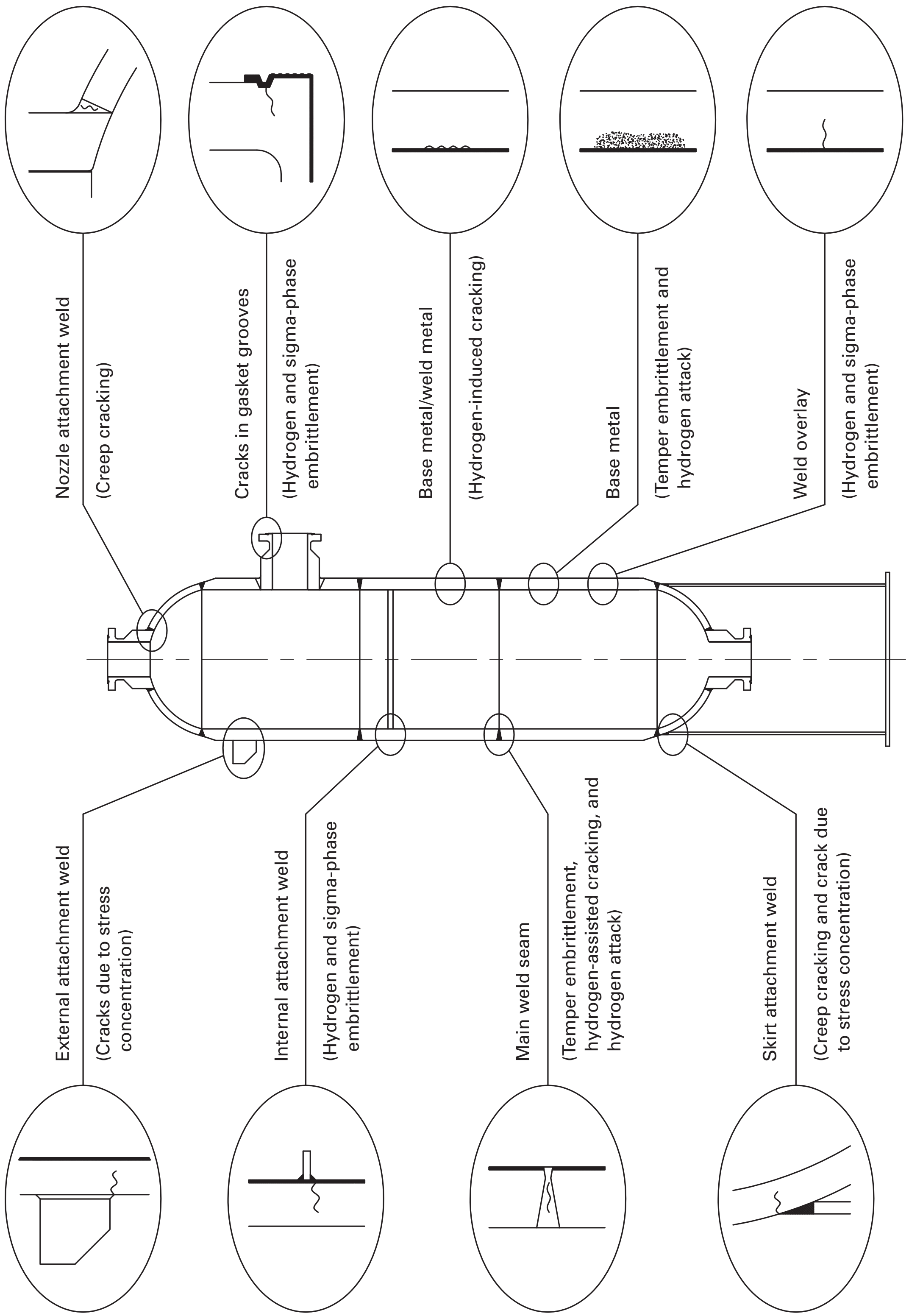

Fig. 3 Flowchart for the Selection of Repair Welding Methods

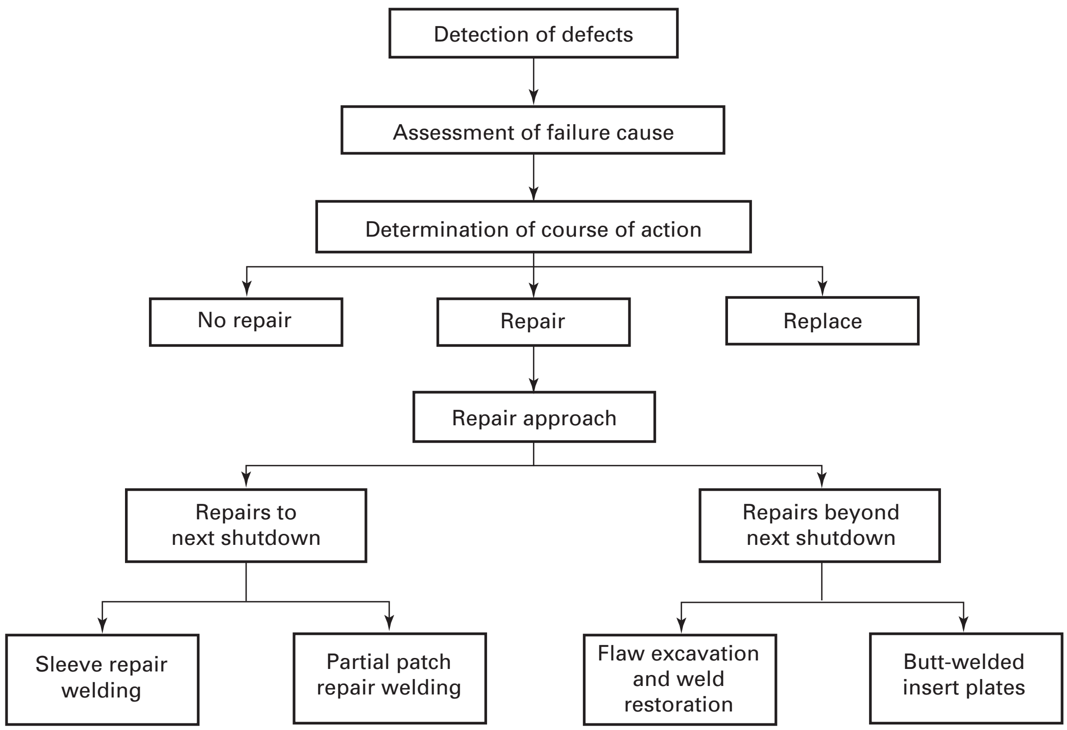

Table 1 Guide for the Selection of Repair Technique

Article Number and Title	General Wall Thinning	Local Wall Thinning	Pitting	Gouges	Blisters	Laminations	Circumferential Cracks	Longitudinal Cracks
2.15 Repair Welding Considerations for Cr–Mo Steel Pressure Vessels	Y	Y	Y	Y	R	R	Y	Y

GENERAL NOTE:
Y = generally appropriate
R = may be used but requires special cautions

Table 2 Cr–Mo Steels Applicable to This Article

	ASME Designation		
Typical Materials	Plates	Forgings	Vessel Piping Components
$1Cr–\frac{1}{2}Mo$	SA-387-12, Cl. 1 and Cl. 2	SA-182-F12 SA-336-F12	SA-335-P12
$1\frac{1}{4}Cr–\frac{1}{2}Mo$	SA-387-11, Cl. 1 and Cl. 2	SA-182-F11 SA-336-F11	SA-335-P11
$2\frac{1}{4}Cr–1Mo$	SA-387-22, Cl. 1 and Cl. 2 SA-542-B, Cl. 4	SA-182-F22, Cl. 1 and Cl. 3 SA-336-F22, Cl. 1 and Cl. 3 SA-541-F22, Cl. 3	SA-335-P22
3Cr–1Mo	SA-387-21, Cl. 1 and Cl. 2	SA-182-F21 SA-336-F21, Cl. 1 and Cl. 3	SA-335-P21
$5Cr–\frac{1}{2}Mo$	SA-387-5, Cl. 1 and Cl.2	SA-182-F5	SA-335-P5
9Cr–1Mo	. . .	SA-182-F9 SA-336-F9	SA-335-P9

Table 3 Typical In-Service Degradation

Type of Damage	Applicable Operating Conditions	Degradation Phenomena	Typical Susceptible Materials
Temper embrittlement [Note (1)]	370°C–580°C (700°F–1,080°F)	Toughness degradation in base metal and welds through the intergranular microsegregation of impurity elements as measured by the J factor for $2\frac{1}{4}$Cr and higher Cr base metals, and the X bar factor for weld metals and for 1Cr and $1\frac{1}{4}$Cr base and weld metals	1Cr–$\frac{1}{2}$Mo $1\frac{1}{4}$Cr–0.5Mo $2\frac{1}{4}$Cr–1Mo 3Cr–1Mo 5Cr–1Mo
Creep embrittlement	Over 454°C (850°F) and with applied load	Carbide precipitation and crack initiation in the coarse grain HAZ of a localized stressed area such as at a nozzle attachment weld	1Cr–$\frac{1}{2}$Mo $1\frac{1}{4}$Cr–$\frac{1}{2}$Mo
Hydrogen attack	HTHP hydrogen environment	Generation of methane bubbles, blisters, and cracks [Note (2)]	Low-Cr materials in high-hydrogen, partial-pressure environment
Hydrogen embrittlement	HTHP hydrogen environment, and start-up and shutdown conditions	Toughness degradation by hydrogen absorption	1Cr–$\frac{1}{2}$Mo $1\frac{1}{4}$Cr–$\frac{1}{2}$Mo $2\frac{1}{4}$Cr–1Mo 3Cr–1Mo
Thermal fatigue	Large temperature gradients during operation, and start-up and shutdown conditions	Fracture crack propagation	All materials

GENERAL NOTE: HAZ = heat-affected zone; HTHP = high temperature, high pressure

NOTES:

(1) Embrittlement manifests at lower temperatures during start-up and shutdown.

(2) See API RP 941.

Table 4 Typical Considerations for Weld Repair of In-Service Degradation

Type of Damage	Main Concerns	Repair Considerations [Note (1)]
Temper embrittlement	Low toughness at start-up and shutdown Operating temperature limits Weldability	De-embrittled heat treatment above 600°C (1,100°F), then rapid cooling Use of welding materials with low impurity levels
Creep embrittlement	Detection by NDE Flaw removal	Elimination of stress riser, and higher-Cr material selection
Hydrogen attack	Detection by NDE Flaw removal	Higher-Cr material selection [Note (2)] Stainless steel weld overlay cladding
Hydrogen embrittlement	Toughness at operating temp Weldability	Dehydrogenation heat treatment above 300°C (570°F), 1 h min. Low-hydrogen welding process

GENERAL NOTE: NDE = nondestructive examination

NOTES:

(1) Table includes prevention/mitigation for repair and/or replacement.

(2) Refer to API RP 941, Nelson chart.

Table 5 ASME PCC-2 Repair Methods Applicable to Cr–Mo Vessels

Types of Repair	Relevant Article in ASME PCC-2	Additional Considerations
Sleeve repair	Article 2.6	Replacement with type B sleeve at the first available opportunity is recommended
Overlay welding and/or internal weld metal buildup	Article 2.11	In case of corrosion metal loss, welding materials shall be selected considering cause of corrosion
Butt-welded insert plates	Article 2.1	Thickness of insert plate shall generally not be thicker than shell or head
Alternatives to PWHT	Article 2.9	Refer to para. 4.7
Alternatives to traditional welding preheat	Article 2.8	. . .

Table 6 Repair Approach Sequence

Sequence	Procedure	Remarks
1. Identification of flaws [Note(1)]	VT for identification of dimension and location, followed by NDE (PT, MT, and UT)	. . .
2. Removal of flaws	Grinding or gouging	Finish grinding is required
3. Examination of groove	MT or PT	Ensure complete removal of defects
4. Repair welding	Preheating [Note (2)]	Temperature shall be measured on both sides at the preheated area [Note (3)]
	Weld repair — See Table 3 — Materials: Use equivalent or better grade of materials than those used during the original shop fabrication — Process: GTAW, SMAW, or FCAW	 — WPS or PQR is required — Low-hydrogen type materials shall be used for SMAW and FCAW processes — Interpass temperature and heat input shall be controlled
	Post-heating by burner, electric resistance, or induction heating	For the prevention of cold cracking
	Surface finishing by grinding	For the removal of stress risers
5. Examination	MT, PT, UT, and RT	Examination shall include neighboring areas outside of the repairs
6. Local PWHT	As required by applicable codes [Note (4)]	It may be necessary to guard against harmful thermal gradients
7. Examination	MT, PT, and hardness checks	Recheck for defects
8. Pressure test	As required by applicable codes	Heat pressure-retaining material before and during pressurization to prevent brittle fracture

GENERAL NOTE:
FCAW = flux-cored arc welding
GTAW = gas tungsten arc welding
MT = magnetic particle testing
PQR = procedure qualification record
PT = penetrant testing
PWHT = postweld heat treatment
RT = radiography
SMAW = shielded metal arc welding
UT = ultrasonic testing
VT = visual examination
WPS = weld procedure specification

NOTES:
(1) Identify flaw size, distribution, location, and depth.
(2) Preheating is mandatory for Cr–Mo steels.
(3) See ASME PCC-2, Article 2.8.
(4) See WRC Bulletin 452 for additional guidelines.

Table 7 Typical Preheat and Interpass Temperatures

Steel	P-No./Group	Minimum Preheating Temperature, °C (°F)	Maximum Interpass Temperature, °C (°F)
1Cr–$^1\!/_2$Mo, 1$^1\!/_4$Cr–$^1\!/_2$Mo	4-1	120 (250)	300 (600)
2$^1\!/_4$Cr–1Mo	5A-1	150 (300)	300 (600)
	5C-1	177 (350)	300 (600)
3Cr–1Mo	5A-1	150 (300)	300 (600)
5Cr–$^1\!/_2$Mo, 9Cr–1Mo	5B-1	200 (390)	300 (600)

Table 8 De-Embrittlement Heat Treatment

Type of Degradation	Materials and Services to Be Considered	De-Embrittlement
Hydrogen attack	All Cr–Mo steels at HTHP hydrogen services	Not applicable due to irreversible phenomena
Creep embrittlement	1Cr–$^1\!/_2$Mo, 1$^1\!/_4$Cr–$^1\!/_2$Mo at over 480°C (900°F)	Not applicable due to irreversible phenomena
Temper embrittlement	2$^1\!/_4$Cr–1Mo, 3Cr–1Mo at 370°C to 580°C (700°F to 1,080°F)	Heating at not less than 600°C (1,120°F)
Hydrogen embrittlement	2$^1\!/_4$Cr–1Mo, 3Cr–1Mo at high-temperature hydrogen services	Dehydrogenation shutdown operation or heat treatment at not less than 300°C (570°F)